European Commission

Screening LCA study : Reusable Menstrual Cup in Europe

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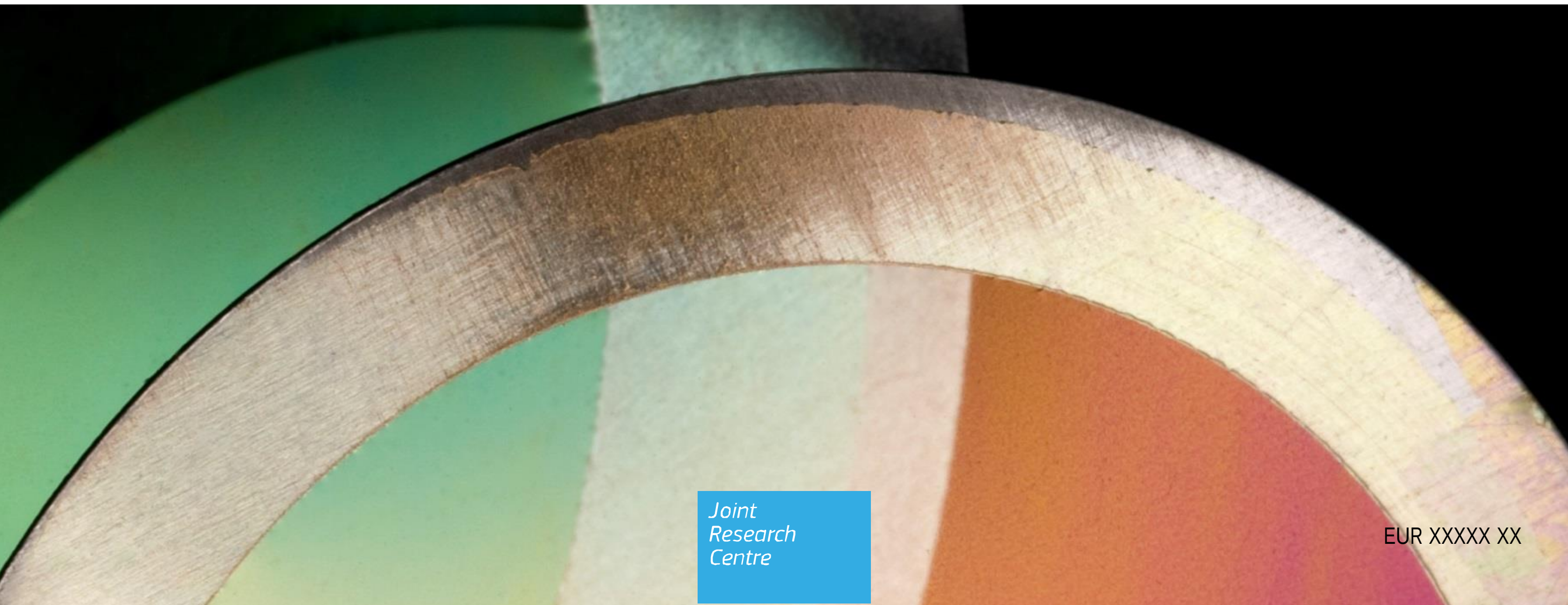

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SUMMARY

The present study is part of an initiative for the revision and update of EU Ecolabel criteria on absorbent hygiene products (AHPs). In 2021 started the process to update the EU Ecolabel criteria for AHPs, for which LCA study of baby diapers and sanitary pads was conducted. Later the product scope was extended to be "Absorbent hygiene products and reusable menstrual cups". The goal of the study is to assess environmental impacts of average reusable menstrual cup, made either from medical grade silicone or thermoplastic elastomer (TPE), using Product Environmental Footprint (PEF) methodology. Results of the assessment will be used to develop new set of EU Ecolabel criteria for RMC. The results are not intended to define thresholds, but to find hotspots for which the criteria should focus on. There is not Product Environmental Footprint Category Rules (PEFCR) for this kind of product, thus this study is performed as a screening study following general PEF methodology rules defined in Zampori & Pant (2019). The study is not intended to define PEF category rules.

Study was conducted by collecting data from RMC manufacturing companies. System boundary includes all life cycle stages from the raw material acquisition to the End of Life. Raw material acquisition includes production of raw materials used in the product manufacturing, production of packaging, and their transport to the manufacturing site. Manufacturing of products includes energy and other inputs used in the manufacturing process and treatment of scraps from the manufacturing process. Distribution includes transport from manufacturing site to the retail and final user. Use phase includes water and soap consumption for washing of hands and cup, as well as water and energy for sterilisation of cup before use and between cycles. End of Life phase includes both the end of life of the main product and packaging. Retail was assumed to have only small impacts, thus retail was excluded from the assessment.

The environmental hotspots identified in this study are related to use phase. More specifically, tap water and soap used to wash hands and cup, as well as in the lower extent wastewater treatment after washing hands and cup, and electricity used for sterilisation of the cup before the first use and between cycles. However, these impacts are strongly related to assumptions of the consumer behaviour and can vary largely between consumers. Assumption of replacement interval was viewed in the sensitivity analysis and it was noticed that increasing interval from 8 hours (baseline scenario) to 12 hours (maximum time between replacements) would decrease the impacts between 15% and 33%. Sensitivity analysis was performed also for lifetime of the cups, and TPE recycling, but both of them had only very limited impact for the total results.

Due to high impact share of the use phase, results were calculated also without. In that case, the production of cotton packaging was identified as a hotspot in almost all relevant impact categories, and in the lower extent also cardboard packaging in some impact categories. In addition, main raw material production, especially silicone was hotspot in some impact categories, i.e. silicone had high relevance in Resource Use – minerals and metals and Human Toxicity –non-cancer impact categories, which were not among the most relevant impact categories when use phase was included. TPE was among the most important impact categories, but with lower importance, due to lower material need for TPE cup.

Data Quality Level is very good (score 2.0) for both RMCs. Although the score is very good, it does not represent well the data quality of the manufacturing of RMCs, because the main contributing processes were related to use phase. Only manufacturing of RMC is based on primary data, all other data is secondary data from databases or literature. To increase the quality of the study, more primary data should be used, especially for the main raw materials used in the manufacturing, i.e. silicone and thermoplastic elastomer. In addition, the representativeness of the manufacturing data is not known, i.e. what are the market shares of the companies that provided data, and market shares of the different cup sizes.

The third-party verification concluded that the study is technically performed correctly. The LCA approach is consistent and compliant with the most recent version of the PEF methodology. Due to the character of the study, not all PEF reporting requirements could be fully met, but this makes no difference to the results. The limitations and representativeness of the conclusions are sufficiently explained, and the study finds and discusses the environmental hotspots in a way that they can be used for the development of ecolabel criteria.

LCIA results of the 10 years of use of an average reusable menstrual cup made of medical grade silicone, which is produced and marketed in the European Union:			
Impact category	Characterized impact	Normalized impact	Weighted impact
Climate Change [kg CO_2 eq.]	1.86E+01	2.30E-03	4.84E-01
Climate Change (fossil) [kg CO_2 eq.]	1.59E+01	-	-
Climate Change (biogenic) [kg CO_2 eq.]	2.51E+00	-	-
Climate Change (LU and LUC) [kg CO_2 eq.]	1.51E-01	-	-
Ozone Depletion [kg CFC-11 eq.]	6.84E-07	1.28E-05	8.05E-04
Ionising Radiation [kBq U^{235} eq.]	1.61E+00	3.82E-04	1.92E-02
Photochemical Ozone Formation [kg NMVOC eq.]	6.19E-02	1.53E-03	7.29E-02
Particulate matter [Disease incidence]	1.53E-06	2.56E-03	2.30E-01
Human toxicity - non-cancer [CTUh]	9.21E-07	4.01E-03	7.38E-02
Human Toxicity - cancer [CTUh]	3.29E-08	1.95E-03	4.15E-02
Acidification [mol of H^+ eq.]	1.17E-01	2.11E-03	1.31E-01
Eutrophication - freshwater [kg P eq.]	5.58E-03	3.47E-03	9.72E-02
Eutrophication - marine [kg N eq.]	1.36E-01	6.95E-03	2.06E-01
Eutrophication - terrestrial [mol N eq.]	4.04E-01	2.29E-03	8.48E-02
Ecotoxicity - freshwater [CTUe]	1.02E+03	2.38E-02	4.58E-01
Land Use [Pt]	7.33E+02	8.95E-04	7.10E-02
Water Use [m^3 world eq.]	9.88E+01	8.62E-03	7.33E-01
Resource Use - fossils [MJ]	1.73E+02	2.66E-03	2.21E-01
Resource Use - mineral and metals [kg Sb eq.]	7.34E-05	1.15E-03	8.70E-02

LCIA results of the 10 years of usage of an average reusable menstrual cup made of thermoplastic elastomer, which is produced and marketed in the European Union:			
Impact category	Characterized impact	Normalized impact	Weighted impact
Climate Change [kg CO_2 eq.]	1.89E+01	2.34E-03	4.93E-01
Climate Change (fossil) [kg CO_2 eq.]	1.63E+01	-	-
Climate Change (biogenic) [kg CO_2 eq.]	2.52E+00	-	-
Climate Change (LU and LUC) [kg CO_2 eq.]	1.58E-01	-	-
Ozone Depletion [kg CFC-11 eq.]	6.90E-07	1.29E-05	8.11E-04
Ionising Radiation [kBq U^{235} eq.]	1.66E+00	3.94E-04	1.97E-02
Photochemical Ozone Formation [kg NMVOC eq.]	6.41E-02	1.58E-03	7.55E-02
Particulate matter [Disease incidence]	1.55E-06	2.60E-03	2.33E-01
Human toxicity - non-cancer [CTUh]	8.73E-07	3.80E-03	6.99E-02
Human Toxicity - cancer [CTUh]	3.51E-08	2.08E-03	4.42E-02
Acidification [mol of H^+ eq.]	1.20E-01	2.16E-03	1.34E-01
Eutrophication - freshwater [kg P eq.]	5.62E-03	3.50E-03	9.79E-02
Eutrophication - marine [kg N eq.]	1.38E-01	7.07E-03	2.09E-01
Eutrophication - terrestrial [mol N eq.]	4.15E-01	2.35E-03	8.72E-02
Ecotoxicity - freshwater [CTUe]	1.02E+03	2.40E-02	4.61E-01
Land Use [Pt]	7.46E+02	9.10E-04	7.23E-02
Water Use [m^3 world eq.]	1.00E+02	8.74E-03	7.44E-01
Resource Use - fossils [MJ]	1.78E+02	2.74E-03	2.29E-01
Resource Use - mineral and metals [kg Sb eq.]	6.89E-05	1.08E-03	8.17E-02

1 Introduction

The EU Ecolabel is a label of environmental excellence that is awarded to products and services meeting high environmental standards throughout their life cycle: from raw material extraction, to production, distribution and disposal. In 2012-2013, Cordella et al. (2013) made a study to define EU Ecolabel criteria for absorbent hygiene products, AHPs. These criteria are published in the Commission Decision (2014/763/EU). According to the Commission Decision (2014/763/EU) the product group 'absorbent hygiene products' "shall comprise baby diapers, feminine care pads, tampons and nursing pads (also known as breast pads), which are disposable and composed of a mix of natural fibres and polymers, with the fibre content lower than 90 % by weight (except for tampons)".

In 2021 started the process to update the EU Ecolabel criteria for AHPs, for which LCA study of baby diapers and sanitary pads was conducted. Later the product scope was extended to be "Absorbent hygiene products and reusable menstrual cups". The goal of this study is to assess environmental impacts of average reusable menstrual cup, made either from medical grade silicone or thermoplastic elastomer (TPE), using Product Environmental Footprint (PEF) methodology. Results of the assessment will be used to develop new set of EU Ecolabel criteria for RMC. The results are not intended to define thresholds, but to find hotspots for which the criteria should focus on.

This study uses LCA approach, more specifically Product Environment Footprint (PEF) method as described in Zampori & Pant (2019). PEF method builds on existing approaches and international standards, but provides more detailed requirements and guidance for modelling the environmental impacts of products. PEF method uses attributional approach, i.e. it estimates what share of the global environmental burdens belongs to a product. The rules provided in PEF method enable to conduct studies that are more reproducible, comparable and verifiable compared to alternative approaches. However, comparability is only possible if the results are based on the same Product Environmental Footprint Category Rules (PEFCR). In case of reusable menstrual cups, there is not any PEFCR available, which means that the study cannot be a full PEF study. Thus, this study is performed as a screening LCA study using manufacturing data from industries, and PEF method as well as PEF compliant datasets as much as possible.

2 Goal of the study

The present study is part of an initiative for the revision and update of the EU Ecolabel criteria on absorbent hygiene products (AHPs), which scope was extended to cover also reusable menstrual cups (RMC). The goal of the study is to assess environmental impacts of an average reusable menstrual cup using PEF methodology to find out the most relevant impacts categories, life cycle stages, processes and flows. Results of the assessment will be used to develop new EU Ecolabel criteria for RMCs. The results are not intended to define thresholds, but to find hotspots for which the criteria should focus on. There is not PEFCR for this type of product, thus this study is performed as a screening study following general PEF methodology rules defined in Zampori & Pant (2019). The study is not intended to define PEF category rules.

The study is targeted for all the stakeholders who are following or involved in the revision of the EU Ecolabel criteria for AHPs and development of new criteria for RMCs, namely AHP and RMC EU Ecolabel applicants and other manufacturers, suppliers of AHP and RMC materials, competent bodies, NGOs, EU Ecolabel board and other EU Commission services.

The study was performed by D3 Land Resources Unit in JRC Ispra with support from B5 Circular Economy and Industrial Leadership in JRC Seville.

3 Scope of the study

3.1 Functional unit and reference flow

The functional unit of the study is ten years of use of the average product produced and marketed in the European Union. The average product is defined using the average composition and weight of the products from companies providing data, with division according to two common raw materials used in the cups; medical grade silicon and thermoplastic elastomer. Thus the functional unit is:

— Ten years of use of reusable menstrual cup made from medical grade silicone based on data from two manufacturing companies (three production sites)

— Ten years of use of reusable menstrual cup made from thermoplastic elastomer (TPE) based on data from one manufacturing company

In case of silicone cup, the Company 1 has two manufacturing sites. Average production of Company 1 is based on average production in these two sites assuming 50% share for both sites, as the volumes of each manufacturing site was not known. After making average of Company 1, the European average was made assuming 50% share of each companies, which data was received (Company 1 and Company 2), because the market shares of the companies were not available. Thermoplastic elastomer is based only on one company data.

According to companies, the silicone cup can be used 10 years, thus reference flow of reusable menstruation cup made from medical grade silicone is one piece. In case of TPE, the use varies between 3 and 5 years (MyCup, 2014). In the base case, 4 years of usage is assumed, thus reference flow of TPE cup is 2.5 pieces. The impact of the use time assumption is reviewed in the sensitivity analysis (Section 7.1).

3.2 System boundary

System boundary includes all life cycle stages from the raw material acquisition to the End of Life (Figure 1). Raw material acquisition includes production of raw materials used in the product manufacturing, production of the packaging, and their transportation to the manufacturing site. Manufacturing stage includes energy and other inputs used in the cup manufacturing process, and treatment of scraps from the manufacturing process. Distribution includes transportation of product from the manufacturing site to the retail and from retail to the end user. Use phase includes water and soap used in the washing of hands and the cup, water and electricity used in the sterilisation of the cup, as well as waste water treatment of the water used in washing and sterilisation. End of Life phase includes both end of life of main product and packaging. Retail was assumed to have only small impacts in the cup life cycle, and is thus excluded from the assessment. No other cut offs were included in the study.

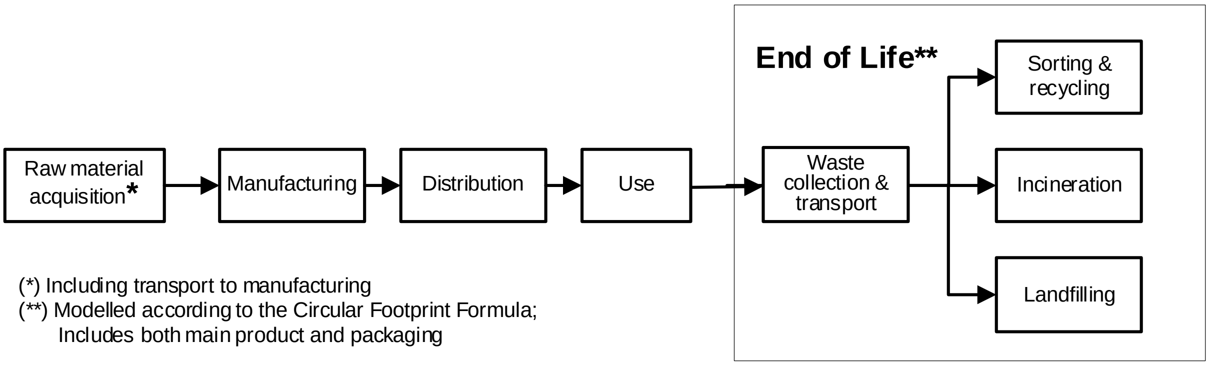

Figure 1: System boundary of reusable menstrual cups.

3.3 Environmental Footprint impact categories

EF 3.0 method, as implemented in SimaPro 9.2 software, was used in the study, with the correction of turbine water flows naming to be corresponding with the flow names in the EF 2.0 database processes. List of impact categories with respective impact category indicators, units and impact assessment models are presented in Table 1. Climate Change results are presented separately for three sub-indicators in the result section.

Table 1: Impact categories with respective impact category indicators, units and impact assessment models used in the assessment.

Impact Category	Impact Category indicator	Unit	Impact Assessment Model
Climate Change, total ([1])	Radiative forcing as Global Warming Potential (GWP_{100})	kg CO_2 eq	Baseline model of the IPCC over a 100 year time horizon (IPCC, 2013)
Ozone Depletion	Increase of stratospheric ozone breakdown as Ozone Depletion Potential (ODP)	kg CFC-11 eq	Steady-state model of the World Meteorological Organization over an infinite time horizon (WMO, 2014 + integrations)
Human Toxicity – cancer	Comparative Toxic Unit for humans (CTU_h)	CTU_h	USEtox model 2.1 (Fankte et al., 2017)
Human Toxicity – non-cancer	Comparative Toxic Unit for humans (CTU_h)	CTU_h	USEtox model 2.1 (Fankte et al., 2017)
Particulate Matter	Impact on human health	Disease incidence	PM method recommended by UNEP (UNEP, 2016)
Ionising Radiation – human health	Human exposure efficiency relative to U^{235}	kBq U^{235} eq	Human Health effect model (Dreicer et al., 1995)
Photochemical Ozone Formation - human health	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model (Van Zelm et al., 2008) as implemented in ReCiPe 2008
Acidification	Accumulated Exceedance (AE) of the critical load	mol H^+ eq	Accumulated Exceedance model (Seppälä et al., 2006; Posch et al., 2008)
Eutrophication – terrestrial	Accumulated Exceedance (AE) of the critical load	mol N eq	Accumulated Exceedance model (Seppälä et al., 2006; Posch et al., 2008)
Eutrophication – freshwater	Fraction of nutrients (P) reaching freshwater end compartment	kg P eq	EUTREND model (Struijs et al., 2009) as implemented in ReCiPe
Eutrophication – marine	Fraction of nutrients (N) reaching marine end compartment	kg N eq	EUTREND model (Struijs et al., 2009) as implemented in ReCiPe
Ecotoxicity –freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model 2.1 (Fankte et al, 2017)
Land Use	• Soil quality index ([2]) • Biotic production • Erosion resistance • Mechanical filtration • Groundwater replenishment	• Dimension less (pt) • kg biotic production • kg soil • m^3 water • m^3 ground-water	Soil quality index based on LANCA (Beck et al., 2010 and Bos et al., 2016)

Impact Category	Impact Category indicator	Unit	Impact Assessment Model
Water Use	User deprivation potential (deprivation-weighted water consumption)	m^3 world eq	Available WAter REmaining (AWARE) as recommended by UNEP, 2016
Resource use – minerals and metals	Abiotic resource depletion (ADP, based on ultimate reserves)	kg Sb eq	CML 2002 (Guinée et al., 2002) as updated in Van Oers et al. (2002)
Resource use –fossils	Abiotic resource depletion –fossil fuels (ADP-fossil)	MJ	CML 2002 (Guinée et al., 2002) and Van Oers et al. (2002)

([1]) The indicator "Climate Change, total" consists of three sub-indicators: Climate Change – fossil; Climate Change – biogenic; and Climate Change – land use and land use change.

([2]) This index is the result of the aggregation, performed by JRC, of the 4 indicators provided by LANCA model as indicators for land use.

3.3.1 Additional environmental information

Biodiversity impacts are mainly related to raw material acquisition. In case of reusable menstrual cups, the raw materials are not known as typical high biodiversity impact materials, and thus biodiversity impacts are not assessed in this study.

3.4 Assumptions and limitations

Main assumptions in the modelling are related to distribution, use phase and End of Life. Distribution of the product and End of Life are modelled according to PEF method, using values and scenarios included in the method (Zampori & Pant, 2019). Use phase is modelled according to literature data, but it depends largely on consumer behaviour. It was also assumed that retail have only small impacts in the RMC life cycle, thus it was not accounted in the assessment.

Limitation of the study are related to data availability, more specifically:

- Only manufacturing process is based on primary data, all other data is secondary data from databases and literature.
- EF database 2.0 was used due to lack of EF 3.0 datasets and therefore secondary data are older. This affects the time representativeness of the secondary dataset.
- The average data of manufacturing of silicone RMC is based only on two companies (three different production sites), without knowledge/taking into account their market share. Also, the companies produce different sizes of RMC, and also market shares of different sizes were not available, and thus could not be taken into account when defining average product. Because of that, the conductor of the study cannot be sure how well the data used in the modelling represents the average product in Europe.
- Only one company provided data on thermoplastic elastomer RMC manufacturing, thus it cannot be considered to represent well average TPE cup.
- The lack of primary data on main material (silicone and TPE) increases the uncertainty on the results of the study, although the impact share of raw materials is very low in all impact categories.

4 Life cycle inventory analysis

Included life cycle stages are following:

- Raw material acquisition (including packaging production, and transport of raw materials and packaging);
- Manufacturing of the product, including disposal of waste produced in the manufacturing site, and transportation of cup from the manufacturing site to the packaging site when applicable (Company 1);
- Distribution of the product from the manufacturing site to the retail and final user;
- Use phase, including hand and cup washing (water and soap), cup sterilisation (water and energy), as well as waste water treatment of water used in washing and sterilisation; and
- End of Life (including both main product and packaging).

Detailed description and modelling choices of each life cycle stage is provided in the following sections. Storage and retail are assumed to have almost zero impact in the total life cycle, and these impacts are not included in the assessment. In addition, potential impacts from additional washing of clothes because of possible leakage is assumed to be small, and it is excluded from the assessment. Capital goods are not otherwise included in the assessment, but in case of use of EF and Ecoinvent datasets, they are included.

Life cycle inventory data received from the companies is confidential data and cannot be published in this report. LCI data is thus included in the Confidential Annex prepared for the verifiers of the study.

4.1 Modelling choices

4.1.1 Raw material acquisition

For the modelling of the production of raw materials used in the reusable menstrual cup manufacturing, secondary data was used from the EF database 2.0. Reusable menstrual cups are made either of medical grade silicone or thermoplastic elastomer (TPE). In addition, pigment can be used to colour the cups, but it is not used in all cases. List of datasets used are presented in Table 2.

Table 2: List of raw materials used in the production of reusable menstrual cup.

Raw material	EF Dataset
Silicone	Silicone, high viscosity {EU-28+EFTA} | hydrolysis and methanolysis of dimethyldichloro silane | production mix, at plant | >30 000 centi Poise | LCI result
TPE	Styrene-butadiene rubber (SBR) {EU-28+EFTA} | Emulsion polymerization of styrene and butadiene | production mix, at plant | 23.5 % styrene | LCI result
Pigment	Iron oxide, red pigment {GLO} | Technology mix | Production mix, at plant | LCI result

Company specific transportation distances for raw materials were used when reported by the company, or estimated according to average distance between production site and country of origin (silicone cups). In case of TPE cup, this information was not available, thus the following EF default scenario from supplier to factory was used:

- 130 km by truck
- 240 km by train
- 270 km by barge

Reusable menstrual cup packaging includes textile bag (made from cotton or micro fibre), cardboard box and user manual made from paper. List of packaging materials and used datasets are presented in Table 3. However, data from Company 3 included information only of the weight of textile bag. The amount of cardboard and paper were added according to data from Company 2, because the actual product weights were similar in those 2 companies, so it was assumed that also amount of packaging materials are similar.

Table 3: List of packaging materials and datasets used for packaging modelling.

Material	Dataset name
Cotton bag	Textile, woven cotton {GLO}| market for | APOS, U (without transport)*
Micro fibre bag	Polypropylene (PP) fibers {EU-28+EFTA} | polypropylene production, spinning | production mix, at plant | 5% loss, 3.5 MJ electricity | LCI result
Cardboard box	Corrugated board, uncoated {EU-28+EFTA} | Kraft Pulping Process, pulp pressing and drying | production mix, at plant | flute thickness 0.8- 2.8 mm, R1=88% | LCI result
Paper (for manual)	Graphic paper {EU-28+3} | production mix | at plant | per kg graphic paper | LCI result

* Ecoinvent 3.6 market for dataset was used to have average market mix of cotton textile, but transport was excluded, and EF transport scenario was used instead as described later.

Cotton bag was assumed to come outside of Europe, thus following EF transport scenario was used:

- 1000 km by truck
- 18000 km by transoceanic container ship

Micro fibre bag, cardboard packaging and paper for manual were assumed to be produced in Europe. The following EF transport scenario for packaging materials was used:

- 230 km by truck
- 280 km by train
- 360 km by barge

4.1.2 Manufacturing

Manufacturing of reusable menstrual cups is based on injection moulding process in the manufacturing company, and it consumes only electricity, in addition to raw materials, according to amounts reported by the manufacturing companies. Country average residual electricity mix was used according to manufacturing country. However, Company 3 did not know the energy consumption per one cup, thus the average electricity consumption per gram of raw material of two other companies were used. According to MyCup (2014), less energy is needed to consume TPE products compared to silicone. Difference was not specified, thus in this study it was assumed to be 20% less. This assumption has very limited effect in the final results, because manufacturing phase has close to zero impact from total impacts. In case of Company 1, manufacturing and packaging takes place in different sites, thus transportation of manufactured RMC from manufacturing site to packaging site was included in the manufacturing stage, using truck transport[1].

Companies 1 and 3 did not report any other outputs beside the main product, however it is acknowledged that during the production process some pieces are discarded on the manufacturing line, for example due to errors in the process. To account this, the same percentage as reported by Vilabrille Paz et al. (2022) was used for all companies. This percentage is applied only to the product without packaging, since the hypotheses is that the pieces are discarded before packaging. This waste material is treated with a worst-case scenario, i.e. using EU average share between landfill[2] and incineration[3], 55% and 45% respectively (Zampori & Pant, 2019), although it is not the likely practise in manufacturing companies. In addition, this amount was added to the raw materials needed in the production including same origin and transportation distances as reported in Section 4.1.1.

4.1.3 Distribution

Distribution from the manufacturing site to the final client is modelled considering the default transport scenario in the PEF method (Zampori & Pant, 2019). The products are first transported to retail stores and from there to the final client. The underlying hypothesis is that 100% of the products are marketed via retail stores, although part of them are probably marketed via online shops. EF scenario of intracontinental supply chain is used from factory to retail, i.e. 3500 km transport from the factory to the retail by truck (100% of products). From retail

[1] Articulated lorry transport, Euro 4, Total weight >32 t (with fuel) {EU-28+3} | diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity | Unit process, single operation

[2] Landfill of plastic waste {EU-28+EFTA} | landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), at landfill site | The carbon and water content are respectively of 62%C and and 0% Water (in weight %) | LCI result

[3] Waste incineration of plastics (unspecified) {EU-28+EFTA} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | unspecified plastic waste | LCI result

to final client the transport distance is 5 km, according to EF scenario, of which 5% is transported by van and 62% by passenger car. The remaining 33% of the products is considered without impacts, i.e. on foot, bike or other human-powered transport. The car travel is representative of the consumer travel to a retail shop (e.g. a supermarket); hence the 5 km are allocated to the product proportionally to items shopped at one time, considering an average shop of 30 items, both food and non-food products (Castellani et al., 2017). Summary of datasets and transport distances per unit of product is presented in Table 6.

Table 4: Summary of the mode of transport, distance and dataset used to model the distribution of products.

Mode of transport	Share of products transported	Distance	EF Dataset
Truck from factory to retail	100%	3500 km	Articulated lorry transport, Euro 4, Total weight >32 t (with fuel) {EU-28+3} | diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity | Unit process, single operation
Car from retail store to final client	62%	5 km	Passenger car, average {GLO} | technology mix, gasoline and diesel driven, Euro 3-5, passenger car | consumption mix, to consumer | engine size from 1,4l up to >2l | LCI result
Van from retail store to final client	5%	5 km	Articulated lorry transport, Euro 3, Total weight <7.5 t (with fuel) {EU-28+3} | diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity | Unit process, single operation

4.1.4 Use phase

Use phase takes into account additional washing of hands before cup is removed/changed, washing the cup after it is removed/changed, and sterilisation of the cup before the first use and between cycles by boiling in the electric stove. Hand washing after removing/changing the cup is not included in the study, because it was assumed that it is the same for all menstrual products. Table 5 presents the EF datasets and amounts used for water, soap and electricity consumption for washing and sterilisation, as well as wastewater treatment of used water. The amounts were calculated using following assumptions:

- Menstruation 13 times per year
- 5 days per cycle
- Cup is replaced every 8 hours[4]
- All water used for washing goes to wastewater treatment.

Same use phase scenario is applied for all menstruation cups, i.e. cups made from silicone and TPE, but in case of sterilisation before use, which has slightly higher energy consumption compared to sterilisation between cycles (longer boiling time) the impact is divided by the lifecycle of one cup, i.e. by 10 years in case of silicone cup, and by 4 years in case of TPE cup.

[4] Cups can be used up to 12 hours, but because of safety reasons, in this study 8 hours is used. Because of the high relevance of the use phase impacts, the sensitivity analysis with different use times is performed (Section 7.2).

Table 5: EF datasets and consumption amounts used in the modelling of the use phase (Vilabrille Paz et al. 2022).

Activity	Amount per one action	EF Dataset
Hand washing, water consumption	0.64 l	Tap water {EU-28+3} | technology mix | at user | per kg water | LCI result
Cup washing, water consumption	1 l	
Cup sterilisation, water consumption	0.65 l	
Hand washing, soap consumption	2.3 g	Soap production {RER} | technology mix | production mix, at plant | 100% active substance | LCI result *
Cup washing, soap consumption	1.88 g	
Cup sterilisation, electricity consumption	0.596 MJ (first use) 0.555 MJ (between cycles)	Residual grid mix {EU-28+3} | AC, technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Wastewater treatment	All water used in hand and cup washing, and sterilisation	Treatment of residential wastewater, large plant {EU-28+EFTA} | waste water treatment including sludge treatment | production mix, at plant | 1m3 of waste water treated | LCI result

* Only production of soap is included, packaging and transportation of soap is excluded.

4.1.5 End of Life

The end of life of the products was modelled using the Circular Footprint Formula (CFF) and considering separate scenarios for the end of life of the product and its packaging. The parameters used in the CFF are:

- R1 is the share of recycled content in the raw materials. This parameter has been considered 0 due to lack of data on the supply chain of materials. The only exceptions are cardboard used for the packaging and paper included in the packaging, which according to the EF dataset used has a recycled content of 88% and 21%, respectively.
- R2 is the share of materials sent to recovery at the end of life of the product. For the disposal of silicone cup, as well as textile and micro fibre bag, it is considered to be 0. For the cardboard packaging and paper included in the packaging, Annex C in PEF method (Zampori & Pant, 2019) provide the average value of R2 in the European market. For the TPE cup, generic plastic packaging R2 value is used, because the lack of actual data, while TPE is fully recyclable as a material.
- R3 is the share of material sent to energy recovery. The European average value of R3 for municipal solid waste to incineration was used for the silicone cup, as well as for textile and micro fibre bag (45%, from Annex C in PEF method (Zampori & Pant, 2019)). For TPE cup, cardboard packaging and paper included in the packaging, the share was calculated as 45%*(1-R2).
- A is the allocation factor of environmental burdens between the supplier and user of recycled material. Lower values allocate more burden on the waste producer. The values suggested in Annex C of the PEF method (Zampori & Pant, 2019) were used.
- Qsout/Qp represents the different quality of the secondary material produced in the recycling process compared to the quality of the virgin material. The values suggested in Annex C of the PEF method (Zampori & Pant, 2019) were used.

The values reported in Table 6 were retrieved from the latest version of Annex C of the PEF method (Zampori & Pant, 2019). The table also report the dataset used for the activity of landfill (E_D), incineration with energy recovery (E_R) and recycling at the end of life ($E_{recyclingEoL}$). However, in reality TPE cups might not end in the recycling, or if they are recycled, the Qsout/Qp ratio would not be as high as assumed in this study. Thus, the impact of these assumptions are reviewed in the sensitivity analysis (Section 7.3). For the recycling activity of cardboard, a custom dataset was created using data on energy consumption in the cardboard production from ecoinvent 3.6 (Wernet et al., 2016). All incineration processes include collection and transport to incineration, while landfilling datasets include only transport, but not collection. Thus 50 km collection with small truck[5] were added for the waste going to landfilling, and 50 km collection and 50 km of transport distance for the recycled fraction of the waste.

Table 6: Summary of the Circular Footprint Formula parameters used in the end of life modelling.

Material	A	R1	R2	R3	Qsout/ Qp	Dataset used
Main product, silicone	-	0%	0%	45%	-	E_R: Waste incineration of plastics (unspecified) {EU-28+EFTA} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | unspecified plastic waste | LCI result
						E_D: Landfill of plastic waste {EU-28+EFTA} | landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), at landfill site | The carbon and water content are respectively of 62%C and and 0% Water (in weight %) | LCI result
Main product, TPE	0.5	0%	29%	32%	0.9	$E_{recyclingEoL}$: 0.6 kWh/kg* of "Residual grid mix {EU-28+3} | AC, technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result"
						E_R: Waste incineration of plastics (unspecified) {EU-28+EFTA} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | unspecified plastic waste | LCI result
						E_D: Landfill of plastic waste {EU-28+EFTA} | landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), at landfill site | The carbon and water content are respectively of 62%C and and 0% Water (in weight %) | LCI result
Textile bag	-	0%	0%	45%	-	E_R: Waste incineration of textile, animal and plant based {EU-28+EFTA} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | textile waste | LCI result
						E_D: Landfill of textile {EU-28+EFTA} | landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), at landfill site | The carbon and water content are respectively of 40%C and and 12% Water (in weight %) | LCI result
Micro fibre bag	-	0%	0%	45%	-	E_R: Waste incineration of plastics (unspecified) {EU-28+EFTA} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | unspecified plastic waste | LCI result

5 Articulated lorry transport, Euro 3, Total weight <7.5 t (with fuel) {EU-28+3} | diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity | Unit process, single operation

						E_D: Landfill of plastic waste {EU-28+EFTA} | landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), at landfill site | The carbon and water content are respectively of 62%C and and 0% Water (in weight %) | LCI result
Paper	0.5	21%	62%	17%	0.85	E_R: Waste incineration of paper and board {EU-28+EFTA} | waste-to-energy plant with dry flue gas treatment including transport and pre-treatment | production mix at consumer | paper waste
						E_D: Landfill of paper and paperboard waste {EU-28+EFTA}
Cardboard packaging	0.2	88%	75%	11%	0.85	$E_{recyclingEoL}$: custom dataset* including: 0.16 kWh/kg* of "Residual grid mix {EU-28+3} | AC, technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result" 0.51 kJ/kg of* "Thermal energy from natural gas {EU-28+3} | technology mix regarding firing and flue gas cleaning | production mix, at heat plant | MJ, 100% efficiency | LCI result"

* Based on ecoinvent 3.6 (Wernet et al., 2016).

4.2 Handling multi-functional processes

There are not any multifunctional processes in the foreground system. The only multifunctional processes are present in the background datasets and are already handled according to the PEF method.

4.3 Data collection

Data on bill of materials, and inputs and outputs in manufacturing stage was collected from RMC manufacturing companies using data collection form provided by JRC. Manufacturing data was received from two companies producing RMC from medical grade silicone, and one company using thermoplastic elastomer. According to the data from individual companies' arithmetic mean data of companies 1 and 2 (silicon-based production) was calculated, without taking into account market shares of the companies. In case of TPE cup, only one company provided data, thus this data was used as it was. However, use phase does not depend on material or size of the RMC, thus same data was used for all companies, based on Vilabrille Paz et al. (2022). Data collected from companies are classified as confidential and cannot be published.

4.4 Data quality requirements and rating

Data Quality Rating (DQR) of the average RMC was assessed using the criteria described in the PEF methodology. The most relevant processes were included in the rating. The data quality assessment uses four criteria that are scored independently from 1 to 5, with 1 being the highest score. The criteria are precision (P), time representativeness (TiR), geographical representativeness (GeR) and technological representativeness (TeR). Then, the score of each dataset is weighted, according to its share of impact, to give the final Data Quality Rating. Data Quality Rating is presented in Table 7 (silicone RMC) and Table 8 (TPE RMC).

The final result is a very good (score 2.0) for both products. However, the most relevant processes are related to use phase, and does not represent the quality of the manufacturing data. In fact, the data quality of main raw materials (silicone and TPE) are lower quality (2.75) due to use of proxy EF datasets.

Table 7: Data Quality Rating of silicone RMC.

Dataset	Weight	TeR	GeR	TiR	P	DQR
Silicone RMC						2.0
Soap production {RER} | technology mix | production mix, at plant | 100% active substance | LCI result	54.9%	2	1	2	3	2.0
Tap water {EU-28+3} | technology mix | at user | per kg water | LCI result	38.1%	2	1	2	3	2.0
Residual grid mix {EU-28+3} | AC, technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result	4.7%	2	1	2	3	2.0
Textile, woven cotton {GLO}| market for | APOS, U	0.9%	2	2	2	3	2.25
Silicone, high viscosity {EU-28+EFTA} | hydrolysis and methanolysis of dimethyldichloro silane | production mix, at plant | >30 000 centi Poise | LCI result	0.6%	4	2	2	3	2.75
Treatment of residential wastewater, large plant {EU-28+EFTA} | waste water treatment including sludge treatment | production mix, at plant | 1m3 of waste water treated | LCI result	0.5%	2	1	2	3	2.0

Table 8: Data Quality Rating of thermoplastic elastomer RMC.

Dataset	Weight	TeR	GeR	TiR	P	DQR
Thermoplastic elastomer RMC						2.0
Soap production {RER} | technology mix | production mix, at plant | 100% active substance | LCI result	54.2%	2	1	2	3	2.0
Tap water {EU-28+3} | technology mix | at user | per kg water | LCI result	37.6%	2	1	2	3	2.0
Residual grid mix {EU-28+3} | AC, technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result	4.9%	2	1	2	3	2.0
Textile, woven cotton {GLO}| market for | APOS, U	1.6%	2	2	2	3	2.25
Treatment of residential wastewater, large plant {EU-28+EFTA} | waste water treatment including sludge treatment | production mix, at plant | 1m3 of waste water treated | LCI result	0.5%	2	1	2	3	2.0
Styrene-butadiene rubber (SBR) {EU-28+EFTA} | Emulsion polymerization of styrene and butadiene | production mix, at plant | 23.5 % styrene | LCI result	0.3%	4	2	2	3	2.75
Corrugated board, uncoated {EU-28+EFTA} | Kraft Pulping Process, pulp pressing and drying | production mix, at plant | flute thickness 0.8- 2.8 mm, R1=88% | LCI result	0.3%	2	2	2	3	2.25
Freight train, average (with fuel) {EU-28+3} | technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity | Unit process, single operation	0.3%	2	1	2	3	2.0

5 Impact assessment results

Tables 9 and 10 presents characterised, normalised and weighted results of 10 years of use of reusable menstruation cups made of medical grade silicon and thermoplastic elastomer, respectively. Characterised results are presented per life cycle stages, and Climate Change sub-categories are reported separately.

Table 9: Characterised, normalised and weighted impacts of 10 years of usage of an average silicone RMC, which is produced and marketed in the European Union.

Impact category	Characterised impact						Normalised impact	Weighted impact
	Raw material acquisition	Manu-facturing	Distribution	Use	End of Life	Total		
Climate Change [kg CO_2 eq.]	2.37E-01	2.78E-03	3.13E-02	1.83E+01	1.13E-02	1.86E+01	2.30E-03	4.84E-01
Climate Change (fossil) [kg CO_2 eq.]						1.59E+01	-	-
Climate Change (biogenic) [kg CO_2 eq.]						2.51E+00	-	-
Climate Change (land use and land use change) [kg CO_2 eq.]						1.51E-01	-	-
Ozone Depletion [kg CFC-11 eq.]	6.12E-09	1.73E-12	7.13E-14	6.78E-07	-1.41E-11	6.84E-07	1.28E-05	8.05E-04
Ionising Radiation [kBq U^{235} eq.]	1.78E-02	1.61E-03	6.92E-05	1.60E+00	-2.57E-03	1.61E+00	3.82E-04	1.92E-02
Photochemical Ozone Formation [kg NMVOC eq.]	1.56E-03	5.52E-06	1.18E-04	6.03E-02	-2.00E-05	6.19E-02	1.53E-03	7.29E-02
Particulate matter [Disease incidence]	1.90E-08	9.20E-11	1.94E-09	1.50E-06	-2.95E-10	1.53E-06	2.56E-03	2.30E-01
Human toxicity - non-cancer [CTUh]	5.80E-08	1.20E-11	1.74E-10	8.63E-07	-2.38E-11	9.21E-07	4.01E-03	7.38E-02
Human Toxicity - cancer [CTUh]	5.92E-10	1.67E-13	6.86E-12	3.23E-08	-1.30E-12	3.29E-08	1.95E-03	4.15E-02
Acidification [mol of H^+ eq.]	2.08E-03	1.30E-05	3.02E-04	1.15E-01	-2.48E-06	1.17E-01	2.11E-03	1.31E-01
Eutrophication - freshwater [kg P eq.]	4.48E-05	1.23E-08	1.02E-07	5.53E-03	3.03E-08	5.58E-03	3.47E-03	9.72E-02
Eutrophication - marine [kg N eq.]	2.22E-03	2.49E-06	6.05E-05	1.34E-01	-1.34E-06	1.36E-01	6.95E-03	2.06E-01
Eutrophication - terrestrial [mol N eq.]	7.95E-03	5.08E-05	1.38E-03	3.94E-01	9.88E-05	4.04E-01	2.29E-03	8.48E-02
Ecotoxicity - freshwater [CTUe]	6.15E+00	1.99E-02	3.71E-01	1.01E+03	-1.65E-01	1.02E+03	2.38E-02	4.58E-01
Land Use [Pt]	1.67E+01	5.12E-03	3.72E-02	7.18E+02	-1.67E+00	7.33E+02	8.95E-04	7.10E-02
Water Use [m^3 world eq.]	1.75E+00	8.18E-03	2.73E-03	9.71E+01	-6.80E-03	9.88E+01	8.62E-03	7.33E-01
Resource Use - fossils [MJ]	2.97E+00	4.23E-02	4.26E-01	1.70E+02	-2.37E-01	1.73E+02	2.66E-03	2.21E-01
Resource Use - mineral and metals [kg Sb eq.]	5.00E-06	5.65E-10	1.80E-09	6.84E-05	-1.37E-08	7.34E-05	1.15E-03	8.70E-02

Table 10: Characterised, normalised and weighted impacts of 10 years of usage of an average thermoplastic elastomer RMC, which is produced and marketed in the European Union.

Impact category	Characterised impact						Normalised impact	Weighted impact
	Raw material acquisition	Manu-facturing	Distribution	Use	End of Life	Total		
Climate Change [kg CO_2 eq.]	4.01E-01	7.35E-03	7.56E-02	1.84E+01	1.59E-02	1.89E+01	2.34E-03	4.93E-01
Climate Change (fossil) [kg CO_2 eq.]						1.63E+01	-	-
Climate Change (biogenic) [kg CO_2 eq.]						2.52E+00	-	-
Climate Change (land use and land use change) [kg CO_2 eq.]						1.58E-01	-	-
Ozone Depletion [kg CFC-11 eq.]	1.16E-08	5.72E-15	1.73E-13	6.78E-07	-1.87E-11	6.90E-07	1.29E-05	8.11E-04
Ionising Radiation [kBq U^{235} eq.]	2.01E-02	5.53E-04	1.66E-04	1.65E+00	-5.45E-03	1.66E+00	3.94E-04	1.97E-02
Photochemical Ozone Formation [kg NMVOC eq.]	3.46E-03	5.20E-06	2.80E-04	6.04E-02	-6.30E-05	6.41E-02	1.58E-03	7.55E-02
Particulate matter [Disease incidence]	3.43E-08	5.77E-11	4.54E-09	1.51E-06	-6.12E-10	1.55E-06	2.60E-03	2.33E-01
Human toxicity - non-cancer [CTUh]	9.09E-09	3.12E-11	4.27E-10	8.64E-07	-4.78E-10	8.73E-07	3.80E-03	6.99E-02
Human Toxicity - cancer [CTUh]	3.08E-09	2.69E-13	1.68E-11	3.23E-08	-3.33E-10	3.51E-08	2.08E-03	4.42E-02
Acidification [mol of H^+ eq.]	4.05E-03	7.41E-06	7.01E-04	1.15E-01	-1.97E-05	1.20E-01	2.16E-03	1.34E-01
Eutrophication - freshwater [kg P eq.]	8.49E-05	1.76E-08	2.55E-07	5.53E-03	1.08E-07	5.62E-03	3.50E-03	9.79E-02
Eutrophication - marine [kg N eq.]	4.40E-03	1.95E-06	1.42E-04	1.34E-01	-8.20E-06	1.38E-01	7.07E-03	2.09E-01
Eutrophication - terrestrial [mol N eq.]	1.69E-02	2.13E-05	3.21E-03	3.95E-01	1.67E-04	4.15E-01	2.35E-03	8.72E-02
Ecotoxicity - freshwater [CTUe]	1.14E+01	2.17E-02	8.99E-01	1.01E+03	-3.63E-01	1.02E+03	2.40E-02	4.61E-01
Land Use [Pt]	3.12E+01	4.74E-04	9.29E-02	7.18E+02	-3.42E+00	7.46E+02	9.10E-04	7.23E-02
Water Use [m^3 world eq.]	3.19E+00	7.09E-04	6.77E-03	9.71E+01	-1.59E-02	1.00E+02	8.74E-03	7.44E-01
Resource Use - fossils [MJ]	5.83E+00	6.77E-02	1.03E+00	1.72E+02	-8.14E-01	1.78E+02	2.74E-03	2.29E-01
Resource Use - mineral and metals [kg Sb eq.]	4.58E-07	1.25E-10	4.43E-09	6.84E-05	-2.07E-08	6.89E-05	1.08E-03	8.17E-02

6 Interpretation of results

The most relevant impact categories, life cycle stages, processes and flows are presented in Tables 11 (silicone cup) and 12 (TPE cup). In these tables, the contribution analysis of impact category was calculated based on the normalised and weighted impacts, whereas characterised results were used to identify the most relevant life-cycle stages, processes and elementary flows. The respective contribution (in %) for each of the life cycle stages, processes and elementary flows refers to the individual contribution for a specific impact category. Negative values were kept as negative to be able to see benefits from End of Life, although the PEF method suggest to use absolute values.

The most important impact categories for both products are: Water Use (24%), Climate Change (16%), Ecotoxicity – freshwater (15%), Particulate Matter (8%), Resource Use – fossils (7%), Eutrophication – marine (7%) and Acidification (4%).

Use phase is the most relevant life cycle phase for both products, having the share between 98% (Acidification) and 99% (Ecotoxicity – freshwater) in case of silicone cups, and 96% (Acidification) and 99% (Ecotoxicity – freshwater) in case of TPE cups. Raw material acquisition have the share around 1-2% in case of silicone cups, and little bit higher, 1-3% in case of TPE cups. Impact of all other life cycle stages are negligible, manufacturing impacts being almost zero for all relevant impact categories.

In case of Water Use, tap water used for the washing of hands and RMC is the most relevant process for both products, with more than 100% contribution (due to negative impacts for example from wastewater treatment when water is returned to environment). In all other impact categories, soap production is the most relevant process, and often also the only relevant process. In case of Climate Change, wastewater treatment after washing hands and RMC was identified as second relevant process, and in case of Resource Use – fossils, electricity used in the households to sterilise the cup before the first use and between cycles.

As use phase was identified as the most relevant life cycle stage with 98-99% share of the impacts, the most relevant impact categories, phases, processes and flows are presented also without use phase in Tables 13 (silicone cup) and 14 (TPE cup). Water Use and Climate Change are still two most important impact categories for both products, with the shares of 24% and 14% (silicone cup), and 28% and 15% (TPE cup). When the use phase is excluded from the assessment, raw material acquisition is the most relevant life cycle stage for all impact categories and both products, with the shares between 84% and 100% (silicone cup), and 80% and 100% (TPE cup).

In case of silicone cup, cotton bag is the most relevant process in Water Use (92%), Climate Change (36%), Eutrophication – marine (80%), Particulate Matter (33%) and Ecotoxicity – freshwater (80%) impact categories, and second relevant in Resource Use –fossils (32%) impact category. Silicone production is the most relevant process in Resource Use – minerals and metals (95%) and Human Toxicity – non-cancer (95%) impact categories, which were not identified among the most relevant life cycle stages when analysing results with the use phase. In some impact categories (i.e. Climate Change, Resource Use – fossils and Particulate Matter), also corrugated board used for packaging was identified among the most relevant processes with the lower share (14%, 14% and 8%, respectively).

In case of thermoplastic elastomer cup, cotton bag is again identified as the most relevant process in many impact categories, namely Water Use (97%), Climate Change (38%), Eutrophication – marine (77%), Ecotoxicity –freshwater (80%) and Acidification (41%), and the second relevant in Resource Use – fossils (32%), Particulate Matter (34%) and Photochemical Ozone Formation (21%). Thermoplastic elastomer production is the most relevant process in Resource Use –fossils impact category (36%), and among the most relevant processes in Climate Change impact category (16%). Also in case of TPE cup, corrugated board packaging was identified among the most relevant processes in Climate Change (17%), Resource Use – fossils (16%), Particulate Matter (10%) and Photochemical Ozone Formation (11%). In addition, also transport processes are among the most relevant processes in some impact categories, mainly train and lorry transports, which is due to the use of EF transport scenarios, which include also train transport, while in case of silicone cup, only lorry transport was reported by the companies.

Table 11: The most relevant impact categories, life cycle stages, processes and elementary flows of silicone RMC.

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
Water Use	24.4%	Use	98.2%	Tap water, EU average	144%	Water, river	137%
		Raw material acquisition	1.8%				
		Distribution	0.0%				
		Manufacturing	0.0%				
		End of Life	0.0%				
Climate Change	16.1%	Use	98.5%	Soap production	49%	Carbon dioxide, fossil	63%
		Raw material acquisition	1.3%				
		Distribution	0.2%	Wastewater treatment	32%	Methane, fossil	15%
		End of Life	0.1%				
		Manufacturing	0.0%				
Ecotoxicity - freshwater	15.2%	Use	99.4%	Soap production	89%	Sulfur to water	35%
		Raw material acquisition	0.6%			Carbofuran to soil	13%
						Pyrene to water	12%
		Distribution	0.0%			Aluminium to soil	9%

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
		Manufacturing	0.0%			Chloride to water	9%
		End of Life	0.0%			Aluminium to air	4%
Particulate Matter	7.6%	Use	98.6%	Soap production	121%	Particulate, <2.5 µm	59%
		Raw material acquisition	1.2%				
		Distribution	0.1%			Ammonia	26%
		Manufacturing	0.0%				
		End of Life	0.0%				
Resource Use - fossils	7.3%	Use	98.1%	Soap production	61%	Energy from natural gas	37%
		Raw material acquisition	1.7%			Energy from coal	23%
		Distribution	0.2%	Electricity, residual mix	21%	Energy from coal	18%
		Manufacturing	0.0%			Energy from uranium	15%
		End of Life	-0.1%				

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
Eutrophication - marine	6.8%	Use	98.3%	Soap production	83%	Nitrate to water	81%
		Raw material acquisition	1.6%				
		Distribution	0.0%				
		Manufacturing	0.0%				
		End of Life	0.0%				
Acidification	4.4%	Use	98.0%	Soap production	90%	Ammonia	50%
		Raw material acquisition	1.8%				
		Distribution	0.3%			Sulfur dioxide	29%
		Manufacturing	0.0%			Nitrogen dioxide	10%
		End of Life	0.0%				

Table 12: The most relevant impact categories, life cycle stages, processes and elementary flows of thermoplastic elastomer RMC.

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
Water Use	24.4%	Use	98.4%	Tap water, EU average	142%	Water, river	135%
		Raw material acquisition	1.6%				
		Distribution	0.0%				
		Manufacturing	0.0%				
		End of Life	0.0%				
Climate Change	16.2%	Use	99.3%	Soap production	49%	Carbon dioxide, fossil	64%
		Raw material acquisition	0.6%				
		Distribution	0.1%	Wastewater treatment	32%	Methane, fossil	15%
		Manufacturing	0.0%				
		End of Life	0.0%				
Ecotoxicity - freshwater	15.1%	Use	98.1%	Soap production	89%	Sulfur to water	35%
		Raw material acquisition	1.4%			Carbofuran to soil	13%
						Pyrene to water	12%

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
		Distribution	0.4%			Aluminium to soil	9%
		End of Life	0.1%			Chloride to water	9%
		Manufacturing	0.0%			Aluminium to air	4%
Particulate Matter	7.6%	Use	98.7%	Soap production	119%	Particulate, <2.5 µm	59%
		Raw material acquisition	1.1%				
		Distribution	0.2%			Ammonia	26%
		Manufacturing	0.0%				
		End of Life	0.0%				
Resource Use - fossils	7.5%	Use	97.8%	Soap production	59%	Energy from natural gas	36%
		Raw material acquisition	1.8%			Energy from coal	22%
		Distribution	0.5%	Electricity, residual mix	21%	Energy from coal	18%
		Manufacturing	0.0%			Energy from uranium	15%

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
		End of Life	-0.1%				
Eutrophication - marine	6.9%	Use	98.2%	Soap production	82%	Nitrate to water	81%
		Raw material acquisition	1.7%				
		Distribution	0.1%				
		Manufacturing	0.0%				
		End of Life	0.0%				
Acidification	4.4%	Use	97.9%	Soap production	88%	Ammonia	49%
		Raw material acquisition	1.8%				
		Distribution	0.4%			Sulfur dioxide	29%
		Manufacturing	0.0%			Nitrogen dioxide	11%
		End of Life	0.0%				

Table 13: The most relevant impact categories, life cycle stages, processes and elementary flows of silicone RMC without the use phase.

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
Water Use	24.0%	Raw material acquisition	99.8%	Cotton packaging	92.4%	Turbine water in China	228%
		Manufacturing	0.5%				
		Distribution	0.2%				
		End of Life	-0.4%				
Climate Change	13.5%	Raw material acquisition	83.9%	Cotton packaging	36%	Carbon dioxide, fossil	80%
		Distribution	11.1%	Silicone production	29%		
		End of Life	4.0%	Cardboard packaging	14%		
		Manufacturing	1.0%	Passenger car	7%		
Resource Use – minerals and metals	10.9%	Raw material acquisition	100.2%	Silicone production	95%	Silver	34%
		Distribution	0.0%			Lead	24%
		Manufacturing	0.0%			Copper	20%
		End of Life	-0.3%			Gold	11%

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
Human Toxicity – non-cancer	8.6%	Raw material acquisition	99.7%	Silicone production	95%	Mercury to air	95%
		Distribution	0.3%				
		Manufacturing	0.0%				
		End of Life	0.0%				
Resource Use - fossils	7.5%	Raw material acquisition	92.8%	Silicone production	41%	Energy from natural gas	25%
						Energy from oil	22%
		Distribution	13.3%	Cotton packaging	32%	Coal, hard	12%
		Manufacturing	1.3%			Energy from coal	11%
		End of Life	-7.4%	Cardboard packaging	14%	Natural gas	7%
						Crude oil	7%
Eutrophication - marine	6.4%	Raw material acquisition	97.3%	Cotton packaging	80%	Nitrate to water	75%
		Distribution	2.6%				

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
		Manufacturing	0.1%			Nitrogen dioxide to air	16%
		End of Life	-0.1%				
Particulate matter	5.8%	Raw material acquisition	91.6%	Cotton packaging	33%	Particulates, < 2.5 µm	53%
		Distribution	9.4%	Train transport	23%		
		Manufacturing	0.4%	Silicone production	21%	Ammonia	27%
		End of Life	-1.4%	Cardboard packaging	8%		
Ecotoxicity - freshwater	5.3%	Raw material acquisition	96.4%	Cotton packaging	80%	Trichlorfon to soil	22%
						Chloride to water	17%
		Distribution	5.8%			Aluminium to air	14%
		Manufacturing	0.3%			Chlorpyrifos to soil	14%
		End of Life	-2.6%			Azadirachtin to soil	9%
						Aluminium to soil	5%

Table 14: The most relevant impact categories, life cycle stages, processes and elementary flows of thermoplastic elastomer RMC without the use phase.

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
Water Use	27.6%	Raw material acquisition	100.3%	Cotton packaging	97%	Turbine water in China	239%
		Distribution	0.2%				
		Manufacturing	0.0%				
		End of Life	-0.5%				
Climate Change	15.2%	Raw material acquisition	80.2%	Cotton packaging	38%	Carbon dioxide, fossil	79%
		Distribution	15.1%	Cardboard packaging	17%		
		End of Life	3.2%	TPE production	16%	Methane, biogenic	6%
		Manufacturing	1.5%	Passenger car	10%		
Resource Use – fossils	9.2%	Raw material acquisition	95.4%	TPE production	36%	Energy from oil	39%
						Energy from natural gas	21%
		Distribution	16.8%	Cotton packaging	32%	Hard coal	12%
		Manufacturing	1.1%			Natural gas	7%

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
		End of Life	-13.3%	Cardboard packaging	16%	Crude oil	7%
Eutrophication - marine	8.0%	Raw material acquisition	99.7%	Cotton packaging	77%	Nitrate to water	72%
		Distribution	0.3%				
		Manufacturing	0.0%	Train transportation	15%	Nitrogen dioxide to air	20%
		End of Life	0.0%				
Particulate Matter	6.7%	Raw material acquisition	89.6%	Train transportation	36%	Particulates, < 2.5 µm	52%
		Distribution	11.9%	Cotton packaging	34%		
		Manufacturing	0.2%			Ammonia	28%
		End of Life	-1.6%	Cardboard packaging	10%		
Ecotoxicity - freshwater	6.3%	Raw material acquisition	95.4%	Cotton packaging	80%	Trichlorfon to soil	23%
						Chloride to water	20%
		Distribution	7.5%			Aluminium to air	15%

Most relevant impact category	[%]	Most relevant life cycle stage	[%]	Most relevant processes	[%]	Most relevant elementary flows	[%]
		Manufacturing	0.2%			Chlorpyrifos to soil	14%
		End of Life	-3.0%			Azadirachtin to soil	9%
Acidification	6.2%	Raw material acquisition	85.5%	Cotton packaging	41%	Nitrogen dioxide	36%
		Distribution	14.8%	Train transport	27%	Ammonia	33%
		Manufacturing	0.2%			Sulfur dioxide	18%
		End of Life	-0.4%	Lorry transportation	12%		
Photochemical Ozone Formation	5.1%	Raw material acquisition	94.0%	Train transportation	51%	Nitrogen dioxide	62%
		Distribution	7.6%	Cotton packaging	21%		
		Manufacturing	0.1%			Nitrogen oxide	15%
		End of Life	-1.7%	Cardboard packaging	11%	NMVOC	13%

7 Sensitivity analysis

7.1 RMC lifetime

In the baseline scenario, silicone RMC lifetime was assumed to be 10 years according to the information from the manufacturing companies. In some cases the lifetime can be shorter, and thus the impact of this assumption is reviewed in this sensitivity analysis. Figure 2 compares the baseline impacts with the impacts if the lifetime of silicone RMC would be only 5 years, i.e. 2 cups would be needed during the 10 years period used in the study. According to the Figure 2, the impact of the lifetime is very low. This is due to high impacts in the use phase. Only in Resource Use – minerals and metals and Human Toxicity – non-cancer impact categories the impact increase is higher, between 6 and 7%. However, these impact categories are not identified among the most relevant impact categories, when use phase is included.

For TPE cup, the 4 years lifetime was assumed in the baseline, i.e. the use of 2.5 cups during the 10 years period. Figure 3 presents the comparison of the impacts, if the lifetime would be 3 years (3.33 cups) or 5 years (2 cups). Also in case of the TPE cup, the lifetime assumption has only marginal impact, less than 1% in most of the impact categories. Only in case of Human Toxicity – cancer and Photochemical Ozone Formation, the change is around 2% when lifetime is increased or decreased.

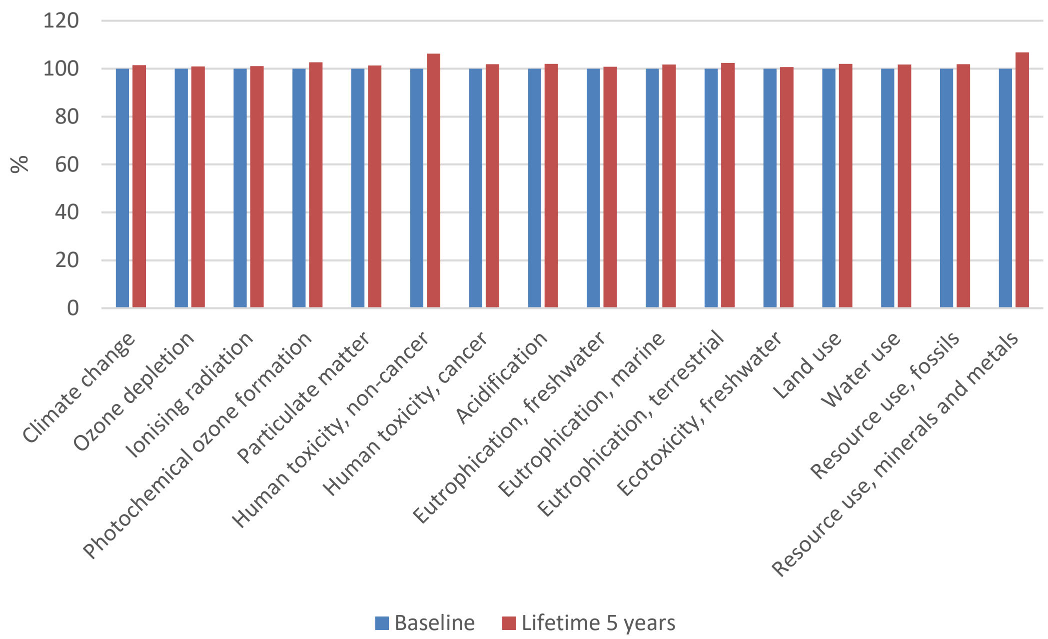

Figure 2: Comparison of silicone RMC impacts, if the lifetime of cup would be 5 years instead of 10 years assumed in the baseline.

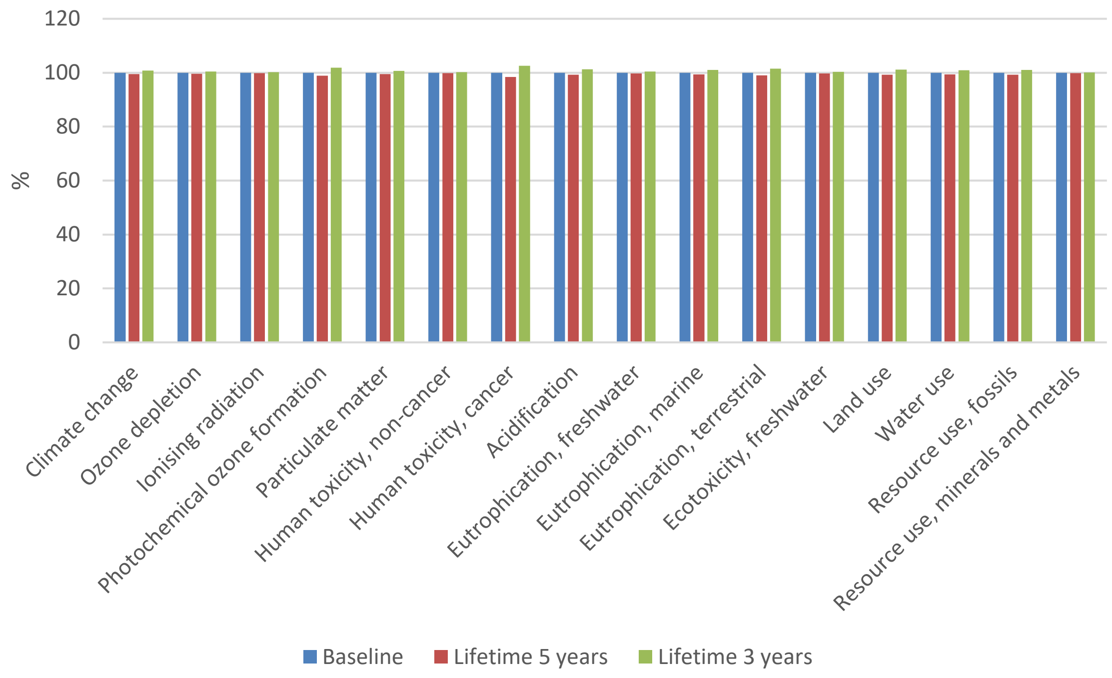

Figure 3: Comparison of thermoplastic elastomer RMC impacts, if the lifetime of cup would be 5 or 3 years instead of 5 years assumed in the baseline.

7.2 RMC replacement interval

In the baseline scenario it was assumed that due to hygienic and safety reasons, cup will be changed/washed every 8 hours, i.e. 3 times per day. However, it should be possible to use cups up to 12 hours, i.e. change/wash it only 2 times per day. As the use phase was the dominating phase in all impact categories, this assumption is reviewed in this sensitivity analysis. Increasing the silicone RMC use time from 8 to 12 hours has a significant impact in all impact categories, between 33% (Ozone Depletion and Land Use) and 16% (Ionising Radiation) (Figure 4). In case of TPE cup, the highest decrease can be noticed in Resource Use – minerals and metals, and Ozone Depletion (33%), and lowest in Resource Use – fossils (15%).

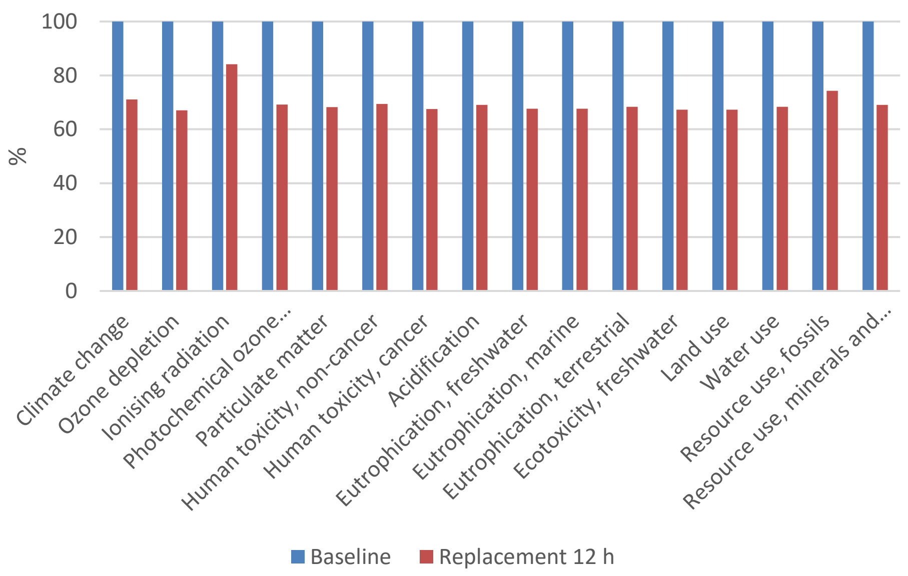

Figure 4: Comparison of silicone RMC impacts, if the cup replacement interval would be 12 hours instead of 8 hours assumed in the baseline.

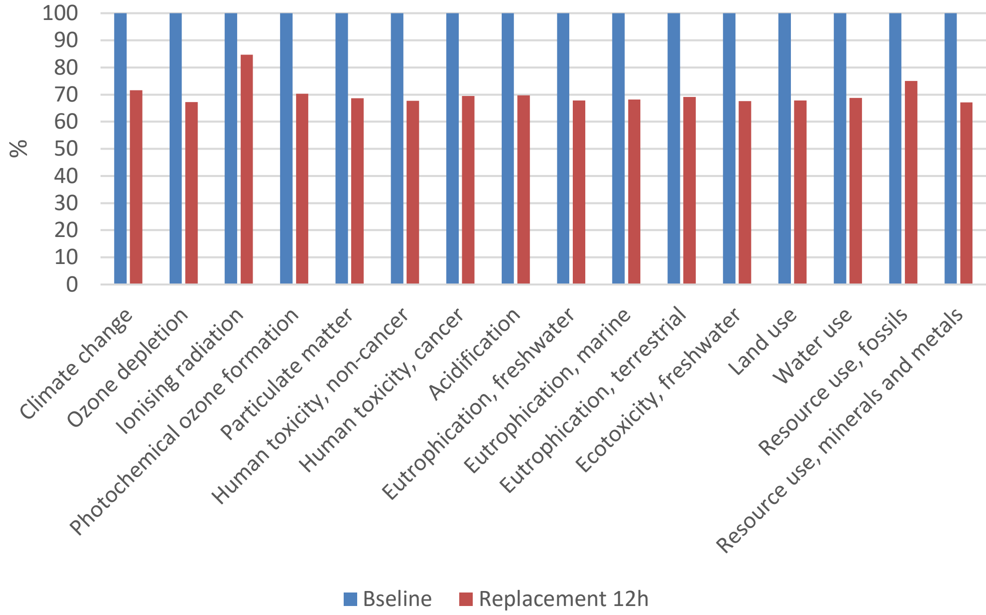

Figure 5: Comparison of thermoplastic elastomer RMC impacts, if the cup replacement interval would be 12 hours instead of 8 hours assumed in the baseline.

7.3 TPE recycling

In the base case, it was assumed that 29% of TPE cups are recycled with Qsout/Qp ratio of 0.9. However, it is not very likely that TPE cups are recycled, or if they are recycled, the quality ratio might be lower than the one used in this study. This sensitivity analysis compares the base line results in the situation in which 1) TPE cups are not recycled, or 2) Qsout/Qp ratio is 0.5. Assumptions related to recycling have very limited impact, less than 1% in all impact categories, being almost zero in the most of the impact categories (Figure 6).

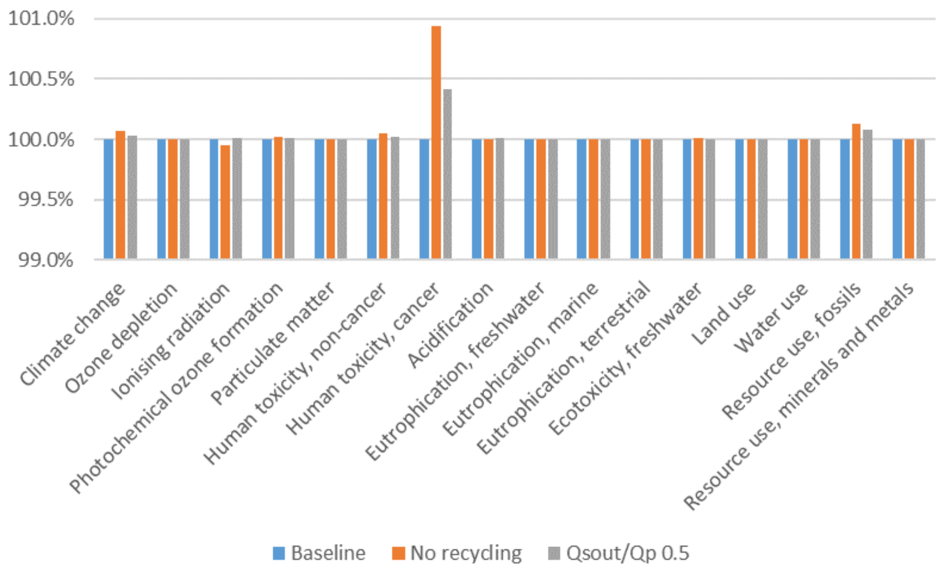

Figure 6: Comparison of TPE menstrual cup results (baseline) with the situation where 1) TPE cups are not recycled, and 2) same amount as baseline is recycled, but Qsout/Qp ratio is 0.5 instead of 0.9. Note that y-axis values does not start from zero.

8 Conclusions

The environmental hotspots identified in this study are related to use phase. More specifically, tap water and soap used to wash hands and cup, as well as in the lower extent wastewater treatment after washing hands and cup, and electricity used for sterilisation of the cup before the first use and between cycles. However, these impacts are strongly related to assumptions of the consumer behaviour and can vary largely between consumers. Assumption of replacement interval was viewed in the sensitivity analysis and it was noticed that increasing interval from 8 hours (baseline scenario) to 12 hours (maximum time between replacements) would decrease the impacts between 15% and 33%. Sensitivity analysis was performed also for lifetime of the cups, and TPE recycling, but both of them had only very limited impact for the total results.

Due to high impact share of the use phase, results were calculated also without. In that case, the production of cotton packaging was identified as a hotspot in almost all relevant impact categories, and in the lower extent also cardboard packaging in some impact categories. In addition, main raw material production, especially silicone was hotspot in some impact categories, i.e. silicone had high relevance in Resource Use – minerals and metals and Human Toxicity –non-cancer impact categories, which were not among the most relevant impact categories when use phase was included. TPE was among the most important impact categories, but with lower importance, due to lower material need for TPE cup.

Results of this study are similar with Vilabrille Paz et al. (2022) study, which also identified use phase as the most relevant life cycle stage with more than 95% share in almost all impact categories (UNEP, 2021). Other studies of reusable menstruation cup included only cup washing with cold water, without taking into account any additional hand washing, soap use or energy for sterilisation, thus the results are different. Hait and Powers (2019) identified transport and use phase as the most relevant life cycle stages, while Leroy et al. (2016) identified packaging and use phase to be the most relevant.

Data Quality Level is very good (score 2.0) for both RMCs. Although the score is very good, it does not represent well the data quality of the manufacturing of RMCs, because the main contributing processes were related to the use phase. Only manufacturing of RMC is based on primary data, all other data is secondary data from databases or literature. To increase the quality of the study, more primary data should be used, especially for the main raw materials used in the manufacturing, i.e. silicone and thermoplastic elastomer. In addition, the representativeness of the manufacturing data is not known, i.e. what are the market shares of the companies that provided data, and market shares of the different cup sizes.

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List of abbreviations

AHP	Absorbent Hygiene Product
CFF	Circular Footprint Formula
DQR	Data Quality Rating
GR	Geographical representativeness
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MSW	Municipal Solid Waste
P	Precision
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
RMC	Reusable menstrual cup
TeR	Technological representativeness
TiR	Time representativeness
TPE	Thermoplastic elastomer

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